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FOREIGN DOCUMENTS OR RADIO BROADCASTS

REPORT

CD NO.

COUNTRY USSR

SUBJECT Scientific - Electronics, magnetic materials, ferrites

HOW PUBLISHED Monthly periodical

WHERE PUBLISHED Moscow

DATE PUBLISHED Dec 1952

LANGUAGE Russian

DATE OF INFORMATION 1952

DATE DIST. 26 Aug 1953

NO. OF PAGES 5

SUPPLEMENT TO REPORT NO.

**UNCLASSIFIED**  
JUN 15 1954  
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SOURCE Radio, No 12, 1952, pp 14-17.

NONMETALLIC MAGNETIC MATERIALS (SOVIET FERRITES)

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Metal magnetic materials, such as silicon transformer steel, which are usually used at low frequencies cannot be used at high frequencies because eddy currents cause power losses proportional to the square of the frequency. To use these materials at high frequencies they must be rolled into sheets 5-10 microns thick. However, producing such thin materials presents difficult engineering problems and, as a result, these materials are very expensive and are not available for wide use.

Experimentation led to the development of magnetodielectrics, which are a pressed mixture of a finely-powdered ferromagnetic with an insulating material. Each particle of magnetic powder, whose size is sometimes measured in microns, is surrounded by a dielectric shell. Because of this shell, eddy currents and losses are small, even at high frequencies. A disadvantage of magnetodielectrics is their low magnetic permeability, due to the demagnetizing effect of gaps between magnetic particles.

Magnetite is a nonmetallic magnetic material often found in nature. Its resistivity is almost 1,000 times greater than that of iron; therefore, losses due to eddy currents are negligible. Cores pressed from magnetite powder have long been used for tuning radio receivers. The magnetic permeability of cylindrical cores is two to three and that of annular types is seven to nine. Magnetodielectrics made from powdered alseifer and carbonyl iron, with permeability from 8 to 30, are widely used in radio.

Materials used in radio must have high permeability (in the hundreds and thousands) with low losses at radio frequencies. Extensive Soviet and foreign research has revealed that if one of the three iron atoms in the cubic crystal lattice of magnetite is replaced by an atom of nickel, manganese, or some other element, materials can be produced with magnetic properties superior to magnetite.

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These materials are called magnetic ferrites. If one of three iron atoms is replaced by an atom of zinc or cadmium in an elementary magnetite cell, non-magnetic ferrites are produced.

The best magnetic properties are found in ferrites which consist of solid solutions of magnetic and nonmagnetic ferrites, such as nickel and zinc ferrites. The process of producing ferrites consists in carefully mixing exact proportions of the oxides of suitable metals, pressing them into the required forms and sizes, then roasting them at temperatures of 1,200-1,400°C.

The nickel-zinc ferrites, produced from the oxides of iron, nickel, and zinc, are of the greatest practical interest in radio engineering.

Ferrites have a fine-grained crystalline structure with a conchoidal fracture and resemble ceramics in that they are quite hard, work poorly with cutting tools, but polish well with abrasives. They have the electrical properties of a semiconductor and a specific resistance of  $10^4 - 10^6$  ohms/cm <sup>[sic]</sup>, that is, the specific resistance is millions of times greater than that of metallic ferromagnetics.

Nickel-zinc ferrites appear to be free of the defects of both sheet magnetic materials and magnetodielectrics, that is, they have high magnetic permeability at radio frequencies with low losses.

#### Basic Properties of Nickel-Zinc Ferrites

The magnetic permeability of ferrites depends primarily on composition and roasting conditions. Their initial magnetic permeability can vary from one to several thousand, and the maximum permeability can reach 6,000-8,000. Nickel-zinc ferrites have low saturation induction of about 2,000-4,000 gauss. Therefore it is expedient to use ferrites only in weak magnetic fields.

Six types of nickel-zinc ferrites have been developed to meet the requirements of high-frequency engineering. They are designated by two letters which denote the composition of the original ferrites and by numbers which indicate the average value of initial magnetic permeability. For example, NTs-500 represents a material which consists primarily of a solid solution of nickel and zinc ferrites and has an initial magnetic permeability of about 500.

Figure 1 <sup>[appended]</sup>, which gives the magnetization curve of three ferrites, shows that in ferrites, as in other magnetic materials, there is a decrease in coercive force with an increase in initial magnetic permeability and also a change in the hysteresis loop, which becomes narrower and steeper.

Magnetic materials lose their magnetic properties when heated above a certain temperature called the Curie point. Iron, for example, loses its magnetic properties at 729°C. Ferrites have a relatively low Curie point. For example, high magnetic permeability types NTs-2500 and NTs-1000 have a Curie point of +80 to +120°C.

Figure 2 <sup>[appended]</sup> shows the change in magnetic permeability of typical ferrites over a wide temperature range. These curves show that the higher the initial permeability, the more it varies with temperature. If the permeability of a ferrite is low, it loses its magnetic properties at higher temperatures.

Studies of ferrites in a wide frequency range showed that the higher the initial magnetic permeability, the more the latter depends on frequency (see Figure 3 <sup>[appended]</sup>). For example, the magnetic permeability of ferrite NTs-500 does not decrease noticeably up to 700 kc; that of ferrite NTs-100, up to 1-1.5 Mc; and that of ferrite NTs-40, up to 2 Mc. In a ferrite with high

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magnetic permeability, such as NTs-2500, the permeability drops sharply at frequencies of 250-300 kc. Figure 3 also shows a curve of the loss tangent  $\tan \delta$  versus frequency for weak fields. It is seen that the lower the permeability of a ferrite, the slower is the increase of loss tangent with increasing frequency.

#### Application of Ferrites

Because of their unusual magnetic and electrical properties, ferrites are of importance in solving certain radio engineering problems which could not be solved with other magnetic materials. Open magnetic cores are characterized by low losses and low magnetic permeability (from units to tens). They are usually used in receivers for high-Q coils as fixed and variable inductances. Closed magnetic cores, characterized by high magnetic permeability and considerably higher losses, are used in transformers and chokes. Nickel-zinc ferrites can be used successfully for these cores.

Ferrite E-shaped cores and armored closed types, used for high-frequency transformers, are shown in Figure 4 not included in this report. In this case, a careful polishing of contact surfaces is important, because the presence of even a small air gap between them reduces the magnetic permeability of the core by 10-30% compared with solid cores. For frequencies of 20-30 kc and above, transformers with ferrite cores are superior to transformers with cores made of expensive thinly rolled permalloy. Ferrite cores are especially useful in the design of wide-band transformers for frequencies above 10 Mc.

Ferrite cores are widely used in radio receivers as fixed and variable inductances in circuit coils and also as filter coils in certain radio equipment and equipment for long-distance wire communications. These coils are usually made with open magnetic cores. Armored cores with a gap, spool-shaped cores, and E-shaped cores with a gap are all used in the lower part of the radio-frequency band. These cores have an effective permeability from 8-10 to 80-100. At frequencies of 0.5 Mc and above, cylindrical and spool-shaped cores with permeability from 2-3 to 10-15 are used.

Ferrite cores permit the highest Q (500-600) in the 50- to 250-kc band. Figure 5 not included in this report shows several types of spool-shaped inductance coils which have a Q of 400-450 at 200 kc.

Ferrite cores can be used as tuning devices in radio receivers for assigned frequencies. With a movable cylindrical ferrite core 4-6 cm long, the coil inductance can be varied 25-30 times. This coil with the movable core is called a ferroinductor. Cores of more complicated forms, such as coaxial or closed coaxial, can be used to construct coils in which the inductance varies more than 100 times.

Figure 6 not included in this report shows a radio model developed in the Leningrad Branch of the Scientific Research Institute of Communications in which the tuning core is made of NTs-250 ferrite. Receivers tuned with ferrite cores are considerably cheaper and smaller than receivers tuned by ganged variable capacitors. Since the magnetic permeability of ferrites, especially of the high permeability type, varies sharply under dc magnetization, this property permits their use as a tuning element of receivers by varying the magnetizing current which passes through a special coil winding. By varying the magnetizing current it is possible to obtain a 100-fold variation of coil inductance.

Ferrites can also be used as open cores in magnetic receiving antennas, as closed cores in high-frequency magnetic amplifiers, and also as nonlinear or impulse coils. The latter are apparently coming into wide use in radio equipment.

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Ferrites, like all other magnetic materials, vary slightly in size (millionths of a millimeter) with a change of magnetic field intensity. This property is known as magnetostriction. By using this property it is possible to make magnetostrictive filters in which the resonators are ferrite cores. Since ferrites vary in resistance when the magnetizing field varies, they can be used as variable resistances (attenuators) in rf circuits.

Ferrites can be used in many other high-frequency applications to replace metal ferromagnetics and magnetodielectrics. However, in replacing metal ferromagnetics with ferrites it is necessary to take into account the operating condition of the material and its specific properties. Otherwise such replacement can lead to negative results.

When ferrites are used in radio equipment, it is necessary to consider the dependence of their magnetic permeability on temperature, their considerable dielectric losses, dependence of the loss tangent on frequency, and low saturation induction. In cases where induction of more than 4,000-5,000 gauss is required, it is not feasible to use ferrites.

[Appended figures follow.]

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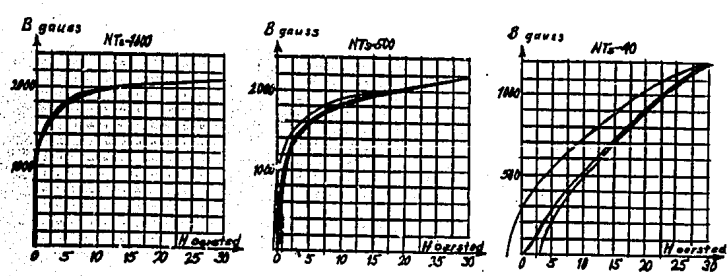


Figure 1. Hysteresis Loops and Magnetization Curves of Several Typical Nickel-Zinc Ferrites

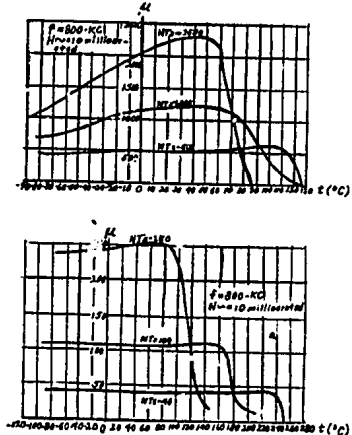


Figure 2. Dependence of Magnetic Permeability  $\mu$  of Various Ferrites on Temperature

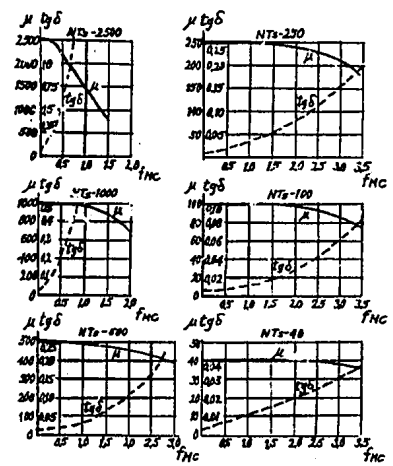


Figure 3. Dependence of Magnetic Permeability  $\mu$  and Loss Tangent  $\tan \delta$  on Frequency in Toroidal Cores 0.5 x 0.3 cm in Cross Section From Various Kinds of Ferrites

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